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Simulation of Development Strategies and Evaluation of Low-Carbon Development Level in Jiangsu Province under Carbon Peaking and Carbon Neutrality Goals

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Abstract: Studies on regional low-carbon development are essential for reducing air pollution, protecting human life and health, and environmental sustainability. In this article, after sorting the connotations of low-carbon development, the low-carbon development evaluation indicators system was constructed, and the entropy weighting method and improved analytic hierarchy process were applied to evaluate the low-carbon development level between 2007 and 2021 about Jiangsu Province, China. Also, the system dynamics model was constructed to simulate the low-carbon development process. The research findings show the following: (1) Low-carbon development in Jiangsu Province obtained some achievement; (2) "Coordination force" played the most crucial role in low-carbon development, while "growth force" and "transformation force" performed better; (3) The simulation results showed that the economic development type would be the most beneficial in the long run; the energy conservation type would be steadily developing and improving every year; and the green transformation type had a clear drive for low-carbon development at an early stage and the impact was rapid. The novelty of this paper includes the following: (1) The dimension division of the index system is novel; (2) The measurement method is novel. The weights of indicators are determined by a combination of the entropy weighting method and improved analytic hierarchy process; (3) The low-carbon development pathways of Jiangsu Province are studied by the system dynamics model. Different strategy conditions are innovatively designed, and simulations of the scenarios are carried out.

Keywords: indicator system; entropy weighting method; system dynamics; sustainability; energy conservation; green transformation

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1. Introduction

Currently, China has set out the plan of achieving carbon peaking by 2030 and working toward carbon neutrality before 2060. On the "China Carbon Neutral 50 Forum 2022 Conference", Xiangwan Du, the academician of the Chinese Academy of Engineering, pointed out that the carbon peaking and carbon neutrality goals ("double carbon" goals) drive China to achieve development transformation and technological innovation, and are the inherent requirements for high-quality economic and social development [1]. The report of the 20th National Congress of the Communist Party of China (a national meeting in China for discussing and deciding important matters) pointed out that promoting social and low-carbon economic development was pivotal for achieving high-quality development, and regions should actively and steadily promote carbon neutrality [2]. Many developed countries have already achieved their carbon peaking targets due to early industrialization, and most are now devoting themselves to the task of carbon neutrality. *The Green Paper on Climate Change: Report on Combating Climate Change (2021)* [3] states that the transition time from carbon peaking to carbon neutrality in developed countries is generally between 50 and 70 years. Comparatively, China's pressure is enormous, as only 30 years have been pledged to realize peak carbon to neutrality. Against this backdrop, it is urgent for China to choose a sustainable, low-carbon, and high-quality development path. Meanwhile, the path found can also be referred to various countries and regions around the world.

As an economically developed province on the eastern coast of China, Jiangsu has a good foundation for low-carbon development, as well as now implementing the “double carbon” goals in a steady and orderly manner. Both the Chinese Government Report and the 14th Five-Year Plan mention the need to respond positively to the carbon peak and neutrality goals. Jiangsu Province is also a major energy-consuming province, accounting for 6.6% of China’s total energy consumption in 2020, and fossil energy is still the main substance of its energy mix, with the proportion of coal consumption as high as 53% in 2020; at the same time, thermal power generation accounts for 85% of total power generation, putting enormous pressure on emissions reduction (data from *Jiangsu Statistical Yearbook 2021, China Energy Statistical Yearbook 2021*). “Achieving carbon neutrality by 2060” is not only a task or a challenge for the future sustainable development of Jiangsu Province, but also an opportunity to give full play to its strengths, make up for its shortcomings, and create new economic growth points. Based on these, an indicator system (in which, the objective is evaluated quantitatively from multiple dimensions and analyzed comprehensively) is established to evaluate the low-carbon development level in Jiangsu Province in the context of the “double carbon” goals, and also a system dynamics model (which can build a simulation system that simulates reality, calculates the result of its change over time, so as to predict the variables, optimizes the selection of schemes, and investigates the impact of variables on the system) is used to simulate the low-carbon development scenarios under different strategies. Finally, some suggestions are provided from the perspectives of adjusting energy structure, optimizing industrial structure, and developing green economy to improve the level of low-carbon development in Jiangsu, to help it achieve “double carbon” goals. This study can provide reference and guidance for air environment protection, urban planning optimization, and sustainable development.

There are five main purposes of this paper which are as follows: (a) Through the form of a literature review, clarifying the connotations of low-carbon development as well as sorting out related index systems and transformation pathways; (b) On the basis of the existing low-carbon development indicator system, constructing a suitable indicator system to comprehensively evaluate the low-carbon development level in Jiangsu; (c) Building a system dynamics model for low-carbon development in Jiangsu Province, and designing different scenarios for simulation; (d) Combined comprehensive evaluation results and system dynamics scenarios simulation results, providing suggestions for the optimization of low-carbon development pathways; (e) Supplementing the quantitative research on low-carbon development under “double carbon” goals, and providing help for other scholars in the future.

The novelty of this paper includes the following: (a) The dimension division of the index system is novel. This study evaluates low-carbon development level from five aspects: growth, transformation, competitiveness, coordination, and sustainability force; (b) The measurement method is novel. The weights of indicators are determined by a combination of the entropy weighting method and the improved analytic hierarchy process; (c) The low-carbon development pathways of Jiangsu Province are studied by the system dynamics model. The system dynamics model is built in combination with the “double carbon” goals, and the low-carbon development scenarios suitable for Jiangsu Province under different strategy conditions are innovatively designed according to its characteristics, and the simulation of scenarios is carried out. Finally, the advantages and disadvantages of each scenario are compared and corresponding suggestions are put forward to help reduce environmental pollution, improve global environmental sustainability, and promote global sustainable development.

The main contributions of this research are the following: (a) The connotation of low-carbon development has been clarified; (b) The evaluation index system of the low-carbon development level in Jiangsu Province has been improved; (c) The application field of system dynamics is expanded; (d) It provides new suggestions for regional low-carbon development and can help policymakers formulate more effective low-carbon development plans and finally promote global sustainable development.

The further material is divided into several parts. Section 2 sorts the relevant literature, and summarizes the definition, evaluation index system, and transformation pathways of low-carbon development. Finally, it elicits the shortcomings of the existing research and the novelty of this study. Section 3 presents the study on the evaluation of low-carbon development level through the construction of an indicator system. Section 4 is the construction and simulation of the low-carbon development system dynamics model. Section 5 is the conclusions and recommendations.

2. Literature Review

2.1. Research on the Connotation of Low-Carbon Development

In the early stage, the UK government introduced the concept of a low-carbon economy with the purpose of combating climate change and contributing to the international climate regime [4]. At that time, the understanding of low-carbon development was simply improving quality of life by using fewer resources and producing less pollution while achieving a higher economic level. Many other countries also supported this idea. Fujino [5] and Strachean [6] also experimented with the possibility that low-carbon development meant that a country should have low emissions while still meeting the demand of its people. Urban et al. pointed out that high energy use efficiency was needed if carbon emissions were to be stabilized at levels that were not climate threatening [7]. Mulugetta et al. classified low-carbon development, which was then an emerging development model, focusing on reducing impact of climate change in the development process, as a part of sustainable development [8].

In the middle stage, scholars further identified energy issues as central to low-carbon development. At that time, Lema proposed that low-carbon development was a process of moving from a fossil-fuel-based energy system toward carbon neutrality [9]. Chen, on the other hand, tested a number of models, finding the significance of renewable energy and identifying energy system transitions as an essential part of low-carbon development [10].

In the present stage, scholars' understanding of low-carbon development is no longer just a superficial effort on greenhouse gas emission reduction, but a new transformation of humanity and the crux to economic high-quality development. Kibria [11] and Kirchherr [12] likewise emphasized that low-carbon development was not only about reducing the impact of climate change and greenhouse gas emissions, but also about a risk in the development program and lifestyles and behaviours of residents which would be changed to form a low-carbon society after comparing different national policies. The digital economy, as a vital contributor to high-quality development, is also one of the significant components of low-carbon development in the new phase. The idea of a low-carbon digital economy was put forward by Xing et al. from the perspective of energy flow, digital flow, and resource flow, which would become the main driver of future economic and social progress [13]. Hu, on the other hand, further complemented the development of it from the angle of digital infrastructure construction and the concept of low-carbon development was enriched [14].

2.2. Research on Dimension Partitioning of the Evaluation Index System of Low-Carbon Development Level

Since the concept of low-carbon development was introduced, scholars have constructed a series of evaluation indicator systems to study the low-carbon development level.

Scholars' research on the evaluation indicator systems of low-carbon development level are mostly hierarchical and systematic in studying index framework from the four major directions of economy, society, environment, and energy. In this paper, by collating the existing relevant literature, as shown in Table 1, the starting perspectives of researchers in constructing the indicator system are categorized into the above four dimensions.

Table 1. Dimensional classification table.

Authors	Economy	Society	Energy	Environment
Wang et al. [15]	Low-carbon economy	Low-carbon society; urban planning	Energy use	Low-carbon environment
Shi et al. [16]	Industrial structure	Lifestyle	Energy structure	Social environment
Zhang et al. [17]	Economy	Transport; urbanism	Energy	Atmospheric environment; water and land resources; pollution control; ecological protection
Tan et al. [18]	Economic aspects	Social life; urban mobility	Energy model	Carbon and the environment; solid waste; water
Lou et al. [19]	Economy-related	Social life; urban mobility	Energy use	Carbon and the environment; solid waste; water; land use
Zhang et al. [20]	Economy	Technology; human resources; markets; policy	Energy	Environment

Apart from dimensions of the low-carbon development index system that have been summarized, there are also some more specific perspectives of construction. For example, Wang et al. analyzed the following six aspects: environmental planning, transport planning, engineering planning, building planning and design, construction management, layout planning, and urban planning, on the basis of which they constructed a low-carbon development indicator system from points of "carbon sink expansion" and "carbon source control" [21]. The price was based on the end-use sector of energy and the system evaluates low-carbon development in several areas such as industry, residence, electricity, commerce, and transport [22]. Tanaka created a low-carbon development indicator system from the angles of demand and supply, combining policy and environment [23].

2.3. Research on the Transformation Pathways of Low-Carbon Development

Various fields such as environment, resources, population, society, economy, and so on are associated with low-carbon development, and it is a complex systemic engineering process to co-ordinate the relationships between them and to build a low-carbon development pathway.

From the angle of industrial restructuring, the transformation of industrial structure is the way to reduce CO_2. The study found that optimizing CO_2 intensity and industrial structure was an effective pathway to low-carbon development [24]. Wu et al. conducted the modelling analysis of the Yangtze River Delta region in China and the results showed that energy demand could be reduced by optimizing industrial structure in Anhui, Zhejiang, and Jiangsu Provinces, and it was an effective way to promote low-carbon development [25]. Chen found that there was a mutually reinforcing effect between low-carbon development and industrial restructuring through a study of low-carbon pilot projects in China [26].

From the angle of energy and structural adjustment, Shi et al. argued that low-carbon development required the integration of new, sustainable, and hybrid energy sources, and predicted the development of high-production efficiency and low carbon in parallel [27]. Lucia and Ericsson illustrated the feasibility of energy transition and its importance in low-carbon development by examining district heating systems in Sweden [28]. Zhang et al. argued that a profound transformation of the energy system was urgently needed to achieve "double carbon" [29].

From the perspective of technological innovation, Bataille et al. delved into the technological and policy deep decarbonization pathways that could make energy-intensive industrial production compliant with *The Paris Agreement* [30]. Foxon demonstrated the significance of innovative low-carbon technologies and social factors in low-carbon development based on business strategies, institutions, technologies, ecosystems, and the coevolution of user practices [31,32]. Wang et al. found that the introduction of "double carbon" would accelerate the integration and innovation of green low-carbon technologies in the future as a means of becoming more resilient to the impacts of climate change [33]. Cai et al. found that the immaturity and high cost of abatement technologies were major constraints to the realization of "double carbon" goals and further technological innovation was needed [34].

From the perspective of institutional innovation, Nader found that governments should establish a low-carbon economic framework, developing carbon capture and storage projects, expanding existing renewable technologies, and then make them integrated into effective systems as well as encouraging innovation [35]. Geels took a political and power perspective and argued for more attention to the instability and decline of fossil fuel regimes in the future [36,37]. Rweyendela et al. argued that strategic environmental assessment would make a major contribution to low-carbon development [38].

2.4. Summary

A review of the existing literature reveals that the research on low-carbon development has gradually matured, from initially focusing on economic growth rates to understanding that low-carbon development is the critical point to high-quality economic development, and continuous exploration of low-carbon reform pathways. Most of the evaluation indicator systems for low-carbon development have been constructed from economic, energy, social, and environmental aspects. The optimization of low-carbon development pathways is revealed mainly from the perspectives of energy adjustment, industrial adjustment, technological innovation, and institutional innovation. However, due to the short period of time since the "double carbon" goals were proposed, research on low-carbon development pathways under this goal is still relatively scarce and mostly from a qualitative perspective, with less quantitative research. Moreover, the dimension division of its index system is relatively simple. Therefore, the future research direction of low-carbon development is able to start from perspective of innovation in index system dimension and strengthening targeted quantitative research.

Based on these, this study establishes a low-carbon development indicator system, so as to evaluate the low-carbon development level of Jiangsu Province, taking into account the actual situation of Jiangsu Province and the existing "double carbon" policy. Meanwhile, this paper also treats the improvement of low-carbon development level under "double carbon" goals as a system engineering process, and uses system dynamics simulation technology to simulate and compare the situation of low-carbon development under different strategies, and try to refine the best optimization pathway.

3. Study on the Evaluation of Low-Carbon Development Level in Jiangsu Province under the Carbon Peaking and Carbon Neutrality Goals

3.1. Construction of the Low-Carbon Development Level Evaluation Indicator System

3.1.1. Selection Principles of Indicators

The construction of a low-carbon development level evaluation indicator system should be based on a number of principles, the main ones of which should include the following:

(1) Systematicness

When constructing an evaluation indicator system of low-carbon development level, one cannot study only one aspect in isolation, but needs to consider it from multiple perspectives and describe it in a comprehensive and specific manner. At the same time, this principle also requires that there is a certain logical relationship between the various indicators.

(2) Representativeness

As low-carbon development covers a wide range of indicators, it is crucial to select the important and representative ones among them.

(3) Operability

When constructing the indicator system, realistic factors should be fully considered. The indicators should be operational and need to be considered for quantifiability, data availability, and comparability of results. In addition, the paper should consider the possibility of the selected indicators participating in the construction of the system dynamics model.

3.1.2. Indicator System Construction

This study evaluates the low-carbon development level from the following five aspects: growth force, transformation force, competitiveness force, coordination force, and sustainability force. The relationships among the "five forces" (the name is inspired by Porter's five forces models [39]) are sorted out by combining with the policies related to "double carbon". Table 2 shows the indicator system of low-carbon development level in Jiangsu Province. Specific data can be found in Appendix A.

Table 2. Indicator system for evaluating low-carbon development level in Jiangsu Province.

Objectives	Primary (First Level) Indicators	Secondary (Second Level) Indicators	Unit	Indicators Number
Low-carbon development level	Growth force	Gross domestic product (GDP) per capita (+)	yuan	X_1
		Industrial upgrading (+)	none	X_2
		Per capita disposable income (+)	yuan	X_3
	Transformation force	Proportion of coal consumption (−)	%	X_4
		Proportion of installed capacity of new energy generation (+)	%	X_5
		Investment in urban environmental infrastructure development (+)	100 million yuan	X_6
	Competitiveness force	Number of green patent applications (+)	pieces	X_7
		Number of industrial waste gas treatment facilities (+)	sets	X_8
		Number of R&D researchers (+)	persons	X_9
	Coordination force	Energy consumption per unit of GDP (−)	tons of standard coal/10 thousand yuan	X_{10}
		Energy conservation and environmental protection expenditure/GDP (+)	%	X_{11}
		Per capita park green area (+)	m^2	X_{12}
	Sustainability force	Per capita comprehensive water consumption (−)	hundred million m^3	X_{13}
		Percentage of days with good air quality (+)	%	X_{14}
		Public transport vehicles per 10,000 people (+)	sets	X_{15}

Note: (+) indicates a positive indicator, (−) indicates an inverse indicator.

The five forces are in a progressive relationship, with the growth force laying a good foundation, providing strong momentum and promoting green transformation; the transformation force continuously optimizing its structure and establishing a low-carbon competitive advantage; the competitiveness force ensuring that it has unique strengths that are stronger than others, such as better green and low-carbon technologies and better talents; the coordination force coordinating the economy with the environment internally and externally, resolving the resistance caused by incoherence and enabling it to develop sustainably;

and finally, the sustainability force ensures the stable and long-term development of society and economy.

The growth force is the basis of urban low-carbon development and is bound up with economic development and industrial characteristics. High-quality development can satisfy the growing needs of people for a finer life, and green and low-carbon development is the key to high-quality development. First of all, green and low-carbon demand will increase with increase of GDP per capita from the perspective of economic development [40]; when economic development reaches a certain level, the optimization of industry is needed, and the low-carbon development in cities will often be accompanied by the change and upgrade of industrial structure (in order to take into account these changes, it is proposed to use the indicator of industrial upgrading, the method of calculation of which will be described in the next subsection); eventually, the change of industrial structure will also drive per capita disposable income to change.

The transformation force reflects the ability to realize low-carbon development through structural optimization in economic development. It includes the ability to transform industry into green [41] (expressed as a reduction in the proportion of coal consumption) and energy into clean [42] (expressed as an increase in the proportion of the installed capacity of new energy generation). It also includes the optimization and transformation of the investment structure [43] (expressed as an increase in investment in environmental infrastructure). This is because the expansion of environmental investment contributes to ecological improvement and low-carbon development.

The competitiveness force reflects the region's own ability to develop low-carbon technologies through more patent applications, more recycling technologies (especially for waste gas), and the increase in the number of high-tech talents as indications of its own technological strength and technological potential. Low-carbon technologies are the main direction of low-carbon development. New low-carbon technologies and human capital support are required in low-carbon energy development, high technology industry development, etc. [44].

The coordination force is the ability to coordinate economy and energy, environment and economy, and society and environment in the course of achieving the "double carbon" goals [45,46]. In the previous sentence, economy is represented by GDP, environment is researched from the perspective of energy conservation and environmental protection, and society can be studied through relative indicators about people (the increase of park green area can be regarded as a kind of environmental protection, and human beings represent the society, so the per capita park green area is the coordination of the relationship between society and the environment).

The sustainability force indicates the internal drive for regional low-carbon development. That is to say, the region has the potential ability for green development to ensure its long-term functioning and sustainability, ultimately creating a virtuous cycle. Sustainability is both the source and the ultimate goal of low-carbon development [47]. Sustainable development is linked to the low-carbon awareness of residents, for example, who take the initiative to conserve water and thus reduce carbon emissions from water production, thus contributing to the low-carbon capacity of the region. At the same time, low-carbon development needs local government's attention, and the increase in public transport is a result of the government's promotion of green mobility. In addition, the sustainable development of the region requires carbon emissions reduction and energy conservation, and the improvement of air quality is a good example of emissions reduction and energy saving.

Taking growth force as the primary dimension of the five forces reflects the bottom-line thinking and shows its root position; from growth to transformation, transformation to competition, competition to coordination, coordination to sustainability, this fully reflects the scientific logical thinking and follows the evolutionary law of low-carbon development; placing the sustainability force at the last position of these five forces is conducive to highlighting its position as the goal and destination.

3.1.3. Data Sources and Processing

The data in this paper are obtained from the Jiangsu Statistical Yearbook (*2008–2022*), China Energy Statistical Yearbook (*2008–2022*), China Environmental Statistical Yearbook (2008–2022), Jiangsu Environmental Status Bulletin (*2008–2022*), Jiangsu Water Resources Bulletin, China National Energy Administration, Ministry of Water Resources of Jiangsu Province, China National Bureau of Statistics and China National Intellectual Property Administration. [Links to websites with some data: 1. https://www.stats.gov.cn/ (accessed on 8 January 2024); 2. http://tj.jiangsu.gov.cn/ (accessed on 8 January 2024); 3. http://jswater.jiangsu.gov.cn/ (accessed on 8 January 2024); 4. https://www.cnipa.gov.cn/ (accessed on 8 January 2024); 5. http://sthjt.jiangsu.gov.cn/ (accessed on 8 January 2024); 6. https://www.nea.gov.cn/ (accessed on 8 January 2024)]. The calculation method of "industrial upgrading" is to divide the tertiary industry output by the secondary industry output. The secondary industry includes the mining, manufacturing, production, and supply of electricity, gas, water, and construction. The tertiary industry refers to the service industry. Therefore, industrial upgrading refers to optimizing the industrial structure and then reducing energy-intensive industries and promoting green and low-carbon industries. The unit of coal consumption is standardized to "standard coal" by using the energy conversion factor of 0.7143 kgce/kg [48] in the general rules for calculating comprehensive energy consumption. In addition, a small part of missing data is obtained by linear interpolation or by substitution of data from adjacent years.

3.2. Research Methods

The improved analytic hierarchy process is used in this study combined with the entropy weighting method to determine weights. In this study, because the evaluation indicator system is a two-level index system, the entropy weighting method is used to determine the weights of the scheme layer to the criterion layer, and the improved analytic hierarchy process is used to assign the weights of the criterion layer to the target layer. On the one hand, it makes the most of the information from the actual measurement data to construct a judgment matrix of the analytic hierarchy process, which improves its scientificity and accuracy, and on the other hand, the combination of the improved analytic hierarchy process and entropy weighting method reduces the influence of the problem that the indicator weights are inconsistent with their real effect by only considering the data discretization.

Comparing with other methods (such as the base criterion method (BCM) [49,50], which has high accuracy and a better consistency ratio), the analytic hierarchy process is more intuitive and can know the structure of each layer more clearly. Then, it can be better combined with the entropy weighting method and increase the scientificity.

3.2.1. Improved Analytic Hierarchy Process

The basic principle of the analytic hierarchy process is to construct a tree-like structure of each factor in a decision problem and analyze the relationship between factors. The traditional analytic hierarchy process is based on constructing a judgement matrix by means of expert scoring, building a mathematical model, calculating the weights of each indicator, and evaluating it. In contrast, the improved analytic hierarchy process in this study is based on the idea that for each of the examined indicators in the same sub-target layer, the judgement matrix can be constructed by simply knowing the relative importance between the two. In this paper, robust principal component analysis [51] is used to calculate the score of each indicator to derive its relative importance in order to construct the judgement matrix, and in the end, to achieve the weight of the criterion layer to the target layer. The feature of robust principal component analysis is that it can better identify outliers and effectively resist the adverse effects of outliers, making the final results more robust than traditional principal components. The specific calculation steps are as follows:

(1) Standardization of indicators

Since the metrics are not directly comparable due to their inconsistent magnitudes, a normalization operation is required first. Additionally, before standardization, because of the existence of inverse indicators, this paper converts them positively, taking the opposite number method. The standardization formula used in this paper is as follows:

$$X_{ij}^* = \frac{X_{ij} - \mu_i}{\sigma_i}(i = 1, 2, \ldots n, j = 1, 2, \ldots, m) \tag{1}$$

where X is the evaluation indicator, X^* is the standardized value, i is the indicator number, j is the year, σ is the standard deviation, and μ is the mean.

(2) Calculating the linear combination coefficient matrix

After deriving the loading matrix, the characteristic roots and the variance explained by all the indicators under the robust principal components through the R language software (v R4.1.1 and the code is in Appendix B), calculating their linear combination coefficients.

$$a_{io} = \frac{r_{io}}{\sqrt{\lambda_o}} \tag{2}$$

where a is the linear combination factor, r is the loading factor, λ is the characteristic root, o is the extracted principal component number.

(3) Calculating the composite score factor

The combined score coefficient is obtained by multiplying the linear combination coefficients separately with the variance explained rate and dividing by the cumulative variance explained rate, the formula is as follows:

$$b_i = \frac{\sum t_{io} a_{io}}{\sum t_{io}} \tag{3}$$

where b is the composite score, t is the variance contribution.

(4) Calculating the importance of each indicator

The composite score is converted to (1)–(9) by normalization to indicate its importance, with the formula

$$c_i = \frac{b_i - \min(b_i)}{\max(b_i) - \min(b_i)} \times 8 + 1 \tag{4}$$

where c is the importance score.

(5) Constructing a hierarchical analysis judgment matrix and calculating the weights

A two-by-two comparison of importance resulted in a final judgement matrix, as follows:

$$p = \begin{pmatrix} 1.000 & 0.801 & 0.959 & 0.814 & 1.096 \\ 1.248 & 1.000 & 1.197 & 1.017 & 1.368 \\ 1.043 & 0.835 & 1.000 & 0.849 & 1.142 \\ 1.228 & 0.984 & 1.178 & 1.000 & 1.345 \\ 0.913 & 0.713 & 0.876 & 0.743 & 1.000 \end{pmatrix} \tag{5}$$

The weights are thus obtained, as shown in the criterion layer in Figure 1.

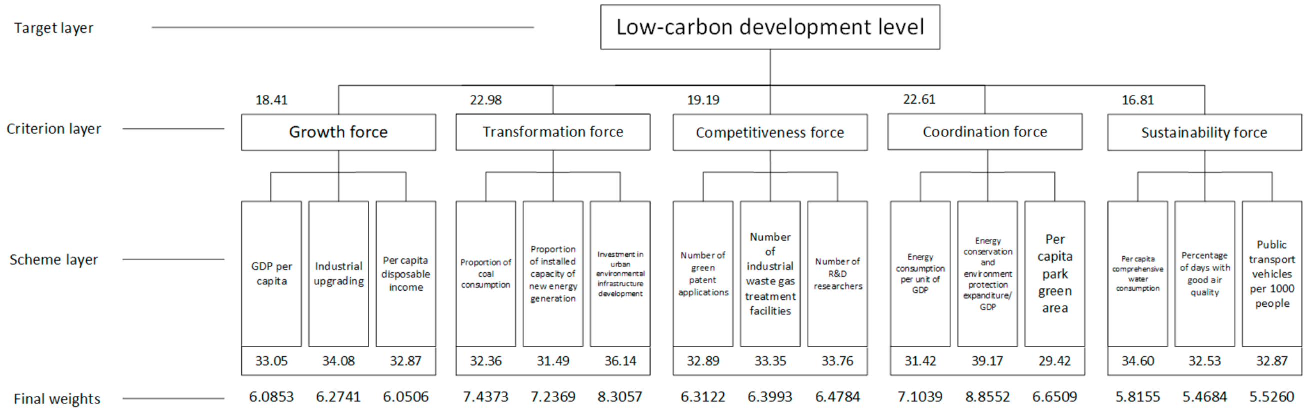

Figure 1. Hierarchical structure model and corresponding weights of the low-carbon development level evaluation in Jiangsu Province (unit: %).

3.2.2. Entropy Weighting Method

The entropy weighting method can be used to calculate the degree of dispersion of a certain index, and it is often used as a basis to determine the index in the comprehensive evaluation. The following are the concrete calculation steps:

(1) Calculating entropy values and their redundancy

$$P_{ij} = \frac{f_{ij}}{\sum\limits_{j=1}^{m} f_{ij}} \tag{6}$$

$$K = \frac{1}{lnm} \tag{7}$$

$$e_i = -K \times \sum_{j=1}^{m} (P_{\rm ij} \times \ln P_{\rm ij}) \tag{8}$$

$$d_i = 1 - e_i \tag{9}$$

where f is the corresponding indicator value after standardization and translation processing, e is the information entropy, and d is the entropy redundancy.

(2) Calculating weights

$$w_i = \frac{d_i}{\sum d_i} \tag{10}$$

In this paper, where w is the weight of each secondary indicator relative to the primary index, the calculation results of the entropy weighting method are shown in the scheme layer of Figure 1.

3.3. Calculating the Low-Carbon Development Level

After combining and multiplying the results of the entropy weighting method and improved analytic hierarchy process, the results as shown in Figure 1 are finally obtained.

This study has calculated the low-carbon development level using a combined weighted approach with the following formula:

$$G_j = \sum (\mathrm{m}_i \times f_{ij}) \tag{11}$$

where G is the low-carbon development level and m is the final weighting of each secondary indicator.

3.4. Results and Discussion of the Evaluation

This index reflects the low-carbon development level of Jiangsu in 2007–2021 in a comprehensive manner, and Table 3 shows the final calculation results.

Table 3. Low-carbon development level in Jiangsu Province in 2007–2021.

Year	Growth Force	Transformation Force	Competitiveness Force	Coordination Force	Sustainability Force	Low-Carbon Development Level
2007	0.28	0.39	0.31	0.17	0.28	1.44
2008	0.31	0.43	0.34	0.46	0.32	1.85
2009	0.34	0.51	0.36	0.64	0.32	2.17
2010	0.38	0.55	0.38	0.54	0.33	2.19
2011	0.43	0.50	0.44	0.59	0.36	2.32
2012	0.46	0.56	0.49	0.64	0.37	2.53
2013	0.51	0.66	0.52	0.73	0.46	2.88
2014	0.55	0.78	0.56	0.74	0.53	3.16
2015	0.59	0.72	0.61	0.87	0.59	3.37
2016	0.64	0.73	0.68	0.80	0.63	3.48
2017	0.68	0.75	0.75	0.79	0.62	3.58
2018	0.72	0.87	0.80	0.78	0.64	3.80
2019	0.77	0.89	0.78	0.86	0.64	3.94
2020	0.80	1.03	0.78	0.81	0.74	4.16
2021	0.83	0.96	0.85	0.76	0.74	4.14

The overall low-carbon development level in Jiangsu Province from 2007 to 2021 is good as can be seen from Table 3, with the level increasing year by year, from 1.44 in 2007 to 4.14 in 2021.

In terms of the five indicators of the first grade, the overall trend is also upwards, with small differences in growth rates between the five. In terms of growth over the fifteen years, the coordination force and transformation force have increased more, by 0.59 and 0.57, respectively. Thinking about average annual growth rates, the coordination force is the most important, at 11.16%, with the growth force in second place at 8.07% (Figure 2). On balance, the coordination force is the most critical and contributes more significantly to low-carbon development, followed by the transformation force and growth force.

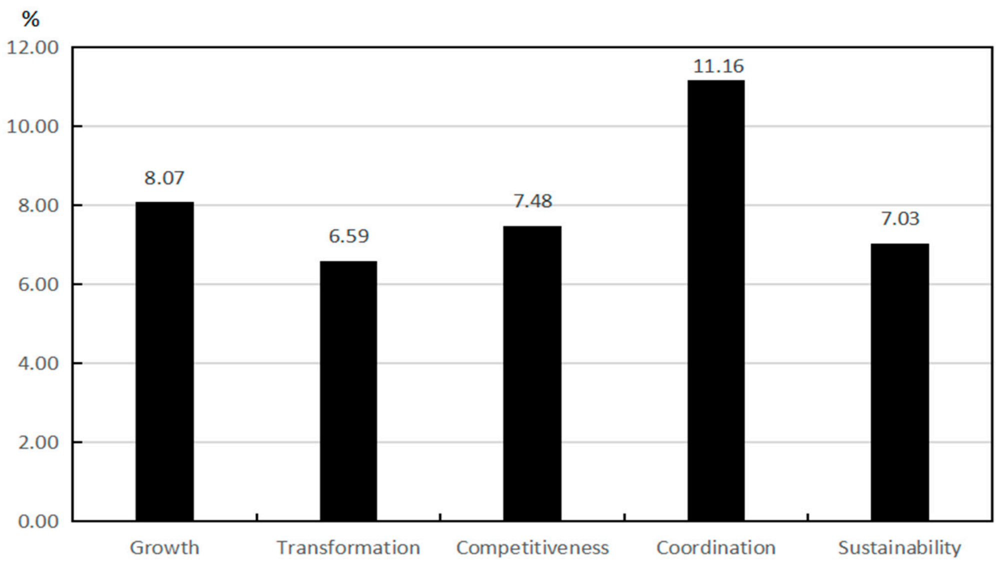

Figure 2. Average annual growth rate of the “five forces” in 2007–2021.

In terms of the second-grade indicators corresponding to the five forces, the highest weights are given to industrial upgrading, investment in urban environmental infrastructure development, number of R&D researchers, energy conservation and environmental protection expenditure/GDP, and per capita comprehensive water consumption. Among all the secondary indicators, the proportion of coal consumption, proportion of installed capacity of new energy generation, investment in urban environmental infrastructure development, energy conservation and environmental protection expenditure/GDP, and energy consumption per unit of GDP have relatively high weights, all exceeding 7%, and can be prioritized to be developed.

4. Construction and Simulations of Low-Carbon Development System Dynamics Model for Jiangsu Province under "Double Carbon" Goals

In order to analyze the overall impact mechanism of low-carbon development in Jiangsu Province, this study constructs a system dynamics model based on the above indicator system, and applies the VENSIM software (Vensim PLE 9.0.1) to simulate the possible development trend by combining historical data and adjusting parameters.

4.1. The Causality Diagram

One of the keys to constructing the system dynamics model is drawing a causality diagram, with the help of which the mechanism of the whole system operation can be clarified and then analyzed in depth. As a complete system, the elements of the low-carbon development process in Jiangsu are not isolated. According to the analysis, it can be known that, first, the increase in GDP per capita will promote industrial restructuring and then increase per capita income. Second, increased green area, new energy inputs, and environmental protection inputs will improve air quality. Third, the increase in researchers will lead to improved green technologies and ultimately higher levels of low-carbon development. From these, a causal diagram is drawn.

Figure 3 shows the causality diagram, where "+" indicates positive feedback, i.e., one side of the arrow has the positive effect on the other side; "−" indicates negative feedback, i.e., one side of the arrow has the negative effect on the other side.

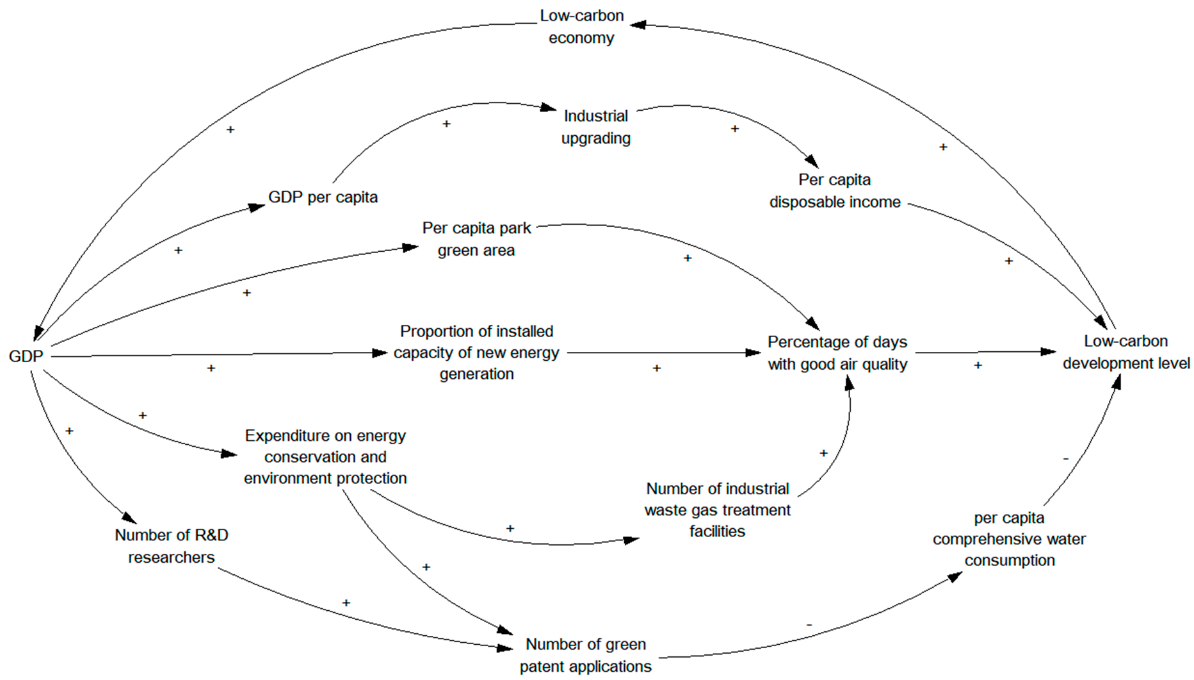

Figure 3. Causality diagram for low-carbon development in Jiangsu Province.

Figure 3 shows that an increase in low-carbon development level will promote a low-carbon economy to develop; in the long run, this will promote economic high-quality development and help biology, information, new materials, and new energy industries to develop more quickly, generating new economic growth points and promoting sustainable economic development, achieving a win–win result.

The causality diagram is constructed based on the above indicator system, so it also starts from the “five forces” driving model, and the following are its main feedback loops:

(1) From the perspective of growth force:

GDP per capita →+ industrial upgrading →+ per capita disposable income →+ low-carbon development level →+ low-carbon economy →+ GDP →+ GDP per capita

(2) From the perspective of transformation force:

Proportion of installed capacity of new energy generation →+ percentage of days with good air quality →+ low-carbon development level →+ low-carbon economy →+ GDP →+ investment in urban environmental infrastructure

(3) From the perspective of competitiveness force:

Number of R&D researchers →+ number of green patent applications →− per capita comprehensive water consumption →− low-carbon development level →+ low-carbon economy →+ GDP →+ number of R&D researchers (The add in green patent applications’ quantity includes the improvement of water-saving technology and water-reuse technology, as well as the enhancement of people’s consciousness of water conservation, which will eventually lead to a gradual reduction in water consumption per capita; then, this will correspondingly reduce water consumption and water pollution emissions, thus reducing carbon emissions from the treatment of sewage and the production and processing of large amounts of water, which can facilitate low-carbon development and refine the ecological environment).

Number of green patent applications →− per capita comprehensive water consumption →− low-carbon development level →+ low-carbon economy →+ GDP →+ expenditure on energy conservation and environmental protection →+ number of green patent applications

(4) From the perspective of coordination force:

Per capita park green area →+ percentage of days with good air quality →+ low-carbon development level →+ low-carbon economy →+ GDP →+ per capita park green area

(5) From the perspective of sustainability force:

Percentage of days with good air quality →+ low-carbon development level →+ low-carbon economy →+ GDP →+ expenditure on energy conservation and environmental protection →+ number of industrial waste gas treatment facilities →+ percentage of days with good air quality

4.2. The System Dynamics Flow Diagram and Main Equations

4.2.1. System Boundaries

In this paper, Jiangsu Province is taken as the research object by the system dynamics simulation model, so the system boundary is low-carbon development level within Jiangsu Province, the time boundary is set to 2011–2030, and the simulation step size is set to 1 year.

4.2.2. System Dynamics Flow Diagram

In this paper, gross domestic product (GDP) and total population are selected as level variables, the amount of GDP growth and population growth are used as rate variables, and number of green patent applications, number of industrial waste gas treatment facilities, industrial upgrading, and per capita disposable income, etc., are used as auxiliary variables to build a system dynamics flow diagram (Figure 4). In total, the model has two level variables, two rate variables, nineteen auxiliary variables, and seven lookup functions.

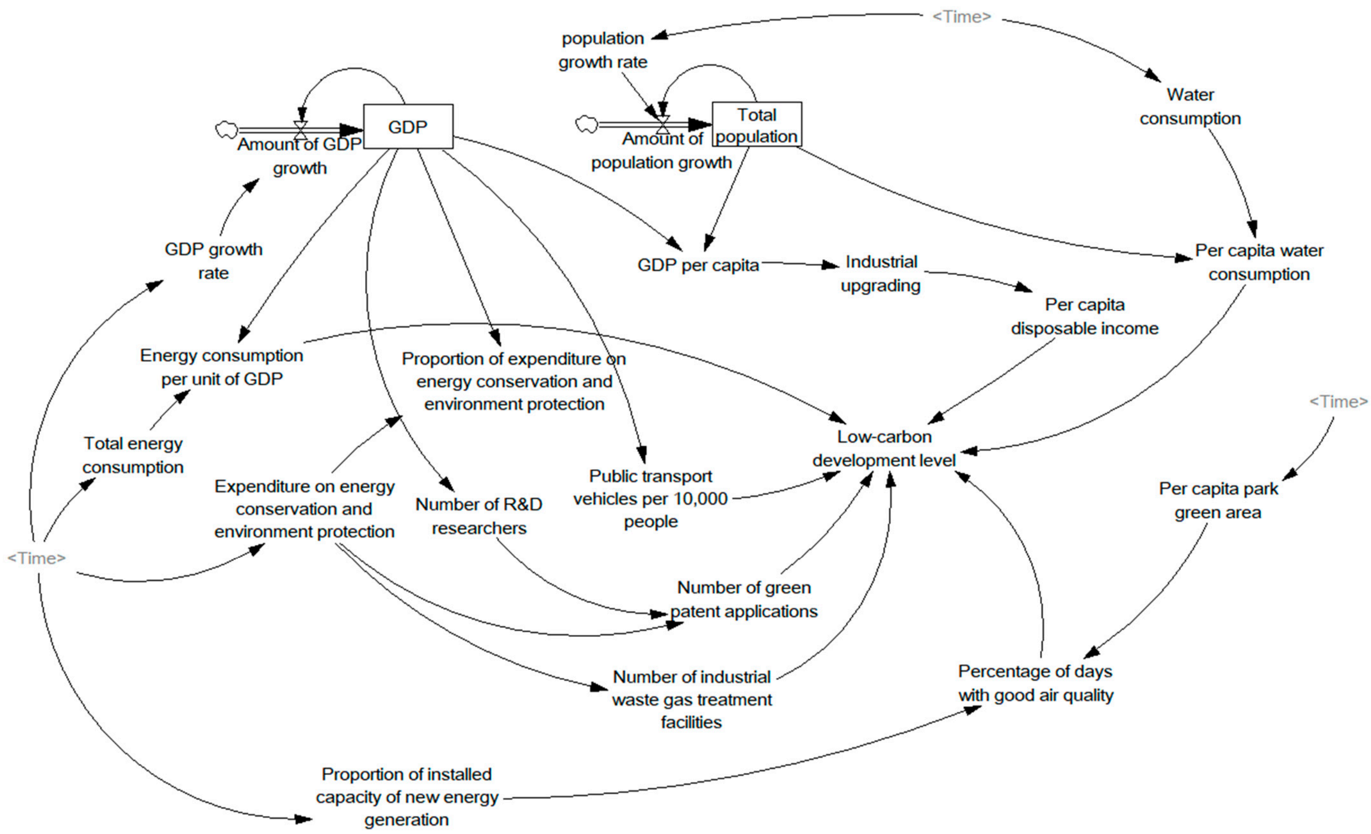

Figure 4. Low-carbon development system dynamics flow diagram for Jiangsu Province.

4.2.3. Model Equations

The quantitative relationships between the variables involved in the system dynamics model in Jiangsu Province are linked through the model equations. The main methods used to determine the equations in this paper are as follows: (i) determined according to economic theory and logistic relationships; (ii) determined using a curvilinear regression model, fitting regressions to historical data from 2007 to 2021; (iii) determined using lookup functions unique to system dynamics as a means of representing non-linear relationships. Meanwhile, some outliers arising from realistic reasons (e.g., changes in measurement standards) are corrected by linear interpolation. The main equations in the flow diagram are as follows:

(1) Level variables

$$GDP = INTEG(amount\ of\ GDP\ growth,\ GDP\ initial\ value) \tag{12}$$

$$Total\ population = INTEG(Total\ population,\ population\ initial\ value) \tag{13}$$

Among them,

$$GDP\ initial\ value = 2598.84\ billion\ yuan$$

$$Population\ inital\ value = 77.23\ million\ people$$

(2) Rate variables

$$Amount\ of\ GDP\ growth = GDP \times GDPgrowthrate \tag{14}$$

$$Amount\ of\ population\ growth = Total\ population \times population\ growth\ rate \tag{15}$$

(3) Auxiliary variables

$$GDP\ per\ capita(yuan) = GDP/Total\ population \times 10,000 \tag{16}$$

$$Energy\ consumption\ per\ unit\ of\ GDP = Total\ energy\ consumption/GDP \tag{17}$$

$$\begin{aligned}&Proportion\ of\ expenditure\ on\ energy\ conservation\ and\ environment\ protection = \\ &Expenditure\ on\ energy\ conservation\ and\ environment\ protection/GDP \times 100\end{aligned} \tag{18}$$

$$Per\ capita\ water\ consumption = Water\ consumption/Total\ population \times 10,000 \tag{19}$$

$$Industrial\ upgrading = EXP(0.457 \times LN(GDP\ per\ capita) - 5.197) \tag{20}$$

$$Per\ capita\ disposable\ income = EXP(2.250 \times LN(Industrial\ upgrading) + 10.294) \tag{21}$$

$$Public\ transport\ vehicles\ per\ 10,000\ people = 8.01 \times 10^{-5} \times GDP + 8.829 \tag{22}$$

$$Number\ of\ R\&D\ researchers = EXP(0.902 \times LN(GDP) + 3.352) \tag{23}$$

$$\begin{aligned}&Number\ of\ green\ patent\ applicaitons = EXP(1.743 \times LN(Number\ of\ R\&D\ researchers) + \\ &0.451 \times LN(Expenditure\ on\ energy\ conservation\ and\ environment\ protection) - 15.671)\end{aligned} \tag{24}$$

$$\begin{aligned}&Number\ of\ industrial\ waste\ gas\ treatment\ facilities = EXP(0.0039 \times LN(Expenditure\ on \\ &energy\ conservation\ and\ environment\ protection) + 8.955)\end{aligned} \tag{25}$$

$$\begin{aligned}&Percentage\ of\ days\ with\ good\ air\ quality = 0.486 \times Proportion\ of\ installed\ capacity\ of \\ &new\ energy\ generation + 6.035 \times Per\ capita\ park\ green\ area - 26.707\end{aligned} \tag{26}$$

4.3. Model Testing

The model is tested through the historical test, which compares the previously established model simulation data with the historical real data to assess its overall validity and accuracy. In this paper, the historical test interval is 2007–2021, and several key variables (number of R&D researchers, industrial upgrading, per capita disposable income, and percentage of days with good air quality) are selected according to the characteristics of the system model for testing. It can be seen in Table 4 that this model has a good simulation effect, which basically has no differences with the actual situation and can be used for in-depth research.

Table 4. Results of model historicity tests.

Year	Number of R&D Researchers (Persons)			Year	Industrial Upgrading		
	Actual Value	Simulation Values	Relative Error (%)		Actual Value	Simulation Values	Relative Error (%)
2007	259,177	274,085	5.75	2007	0.674	0.648	−3.85
2008	315,461	320,819	1.70	2008	0.698	0.701	0.33
2009	369,403	353,602	−4.28	2009	0.732	0.734	0.28
2010	406,231	416,965	2.64	2010	0.783	0.795	1.49
2011	455,135	484,176	6.38	2011	0.820	0.850	3.62
2012	549,159	527,469	−3.95	2012	0.859	0.883	2.84
2013	626,882	577,272	−7.91	2013	0.918	0.920	0.29
2014	676,526	625,174	−7.59	2014	0.972	0.954	−1.87
2015	699,614	680,795	−2.69	2015	1.017	0.994	−2.25
2016	761,046	733,110	−3.67	2016	1.092	1.028	−5.86
2017	754,228	805,538	6.80	2017	1.091	1.076	−1.42
2018	794,123	867,373	9.22	2018	1.114	1.116	0.14
2019	897,701	913,013	1.71	2019	1.169	1.144	−2.16
2020	914,510	947,614	3.62	2020	1.202	1.165	−3.09
2021	1,088,300	1,060,000	−2.63	2021	1.156	1.231	6.48
Year	**Per Capita Disposable Income (yuan)**			**Year**	**Percentage of Days with Good Air Quality (%)**		
	Actual Value	**Simulation Values**	**Relative Error (%)**		**Actual Value**	**Simulation Values**	**Relative Error (%)**
2007	11,574	11,147.9	−3.68	2007	49.7	49.7	0.04
2008	13,237	13,270.5	0.25	2008	51.4	53.1	3.26
2009	14,653	14,733.5	0.55	2009	53.2	53.8	1.19
2010	17,006	17,642	3.74	2010	55.1	54.6	−0.91
2011	19,820	20,506	3.46	2011	57.0	55.2	−3.23
2012	22,432	22,331.9	−0.45	2012	59.0	57.4	−2.72
2013	24,776	24,525.4	−1.01	2013	60.3	60.5	0.25
2014	27,173	26,562.9	−2.25	2014	64.2	63.8	−0.60
2015	29,539	29,150.2	−1.32	2015	66.8	66.2	−0.86
2016	32,070	31,459	−1.91	2016	70.2	68.5	−2.41
2017	35,024	34,846.1	−0.51	2017	68.0	71.1	4.51
2018	38,096	37,806.7	−0.76	2018	68.0	71.1	4.50
2019	41,400	39,971.3	−3.45	2019	71.4	73.8	3.33
2020	43,390	41,661.3	−3.98	2020	81.0	77.6	−4.25
2021	47,498	47,163.1	−0.71	2021	82.4	81.4	−1.18

4.4. Scenario Analysis

4.4.1. Basic Scenario Simulation

In the base scenario, no parameter adjustments are made to variables, and simulation results are directly run and obtained for the period 2007–2030 in the system. The simulation results for some of these variables are as follows. Figure 5 shows the simulation results for its low-carbon development level, while Figures 6 and 7 show the statistical graphs of GDP and energy consumption per unit of GDP after the run, respectively.

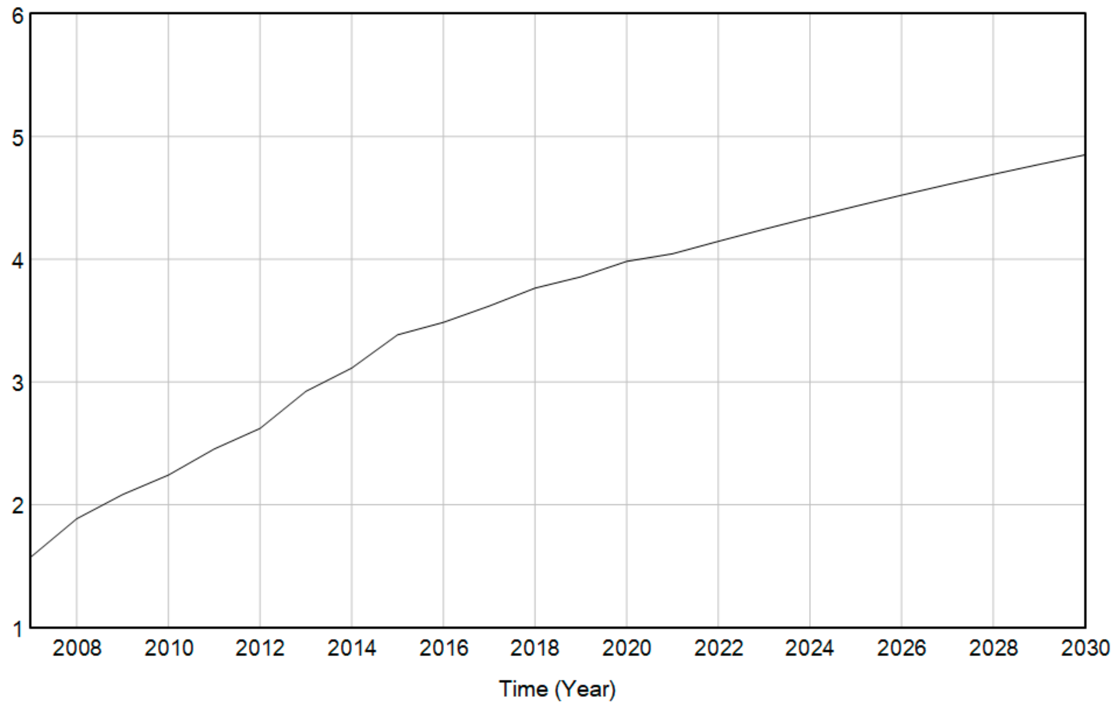

Figure 5. Simulation of the low-carbon development level of basic scenarios for Jiangsu.

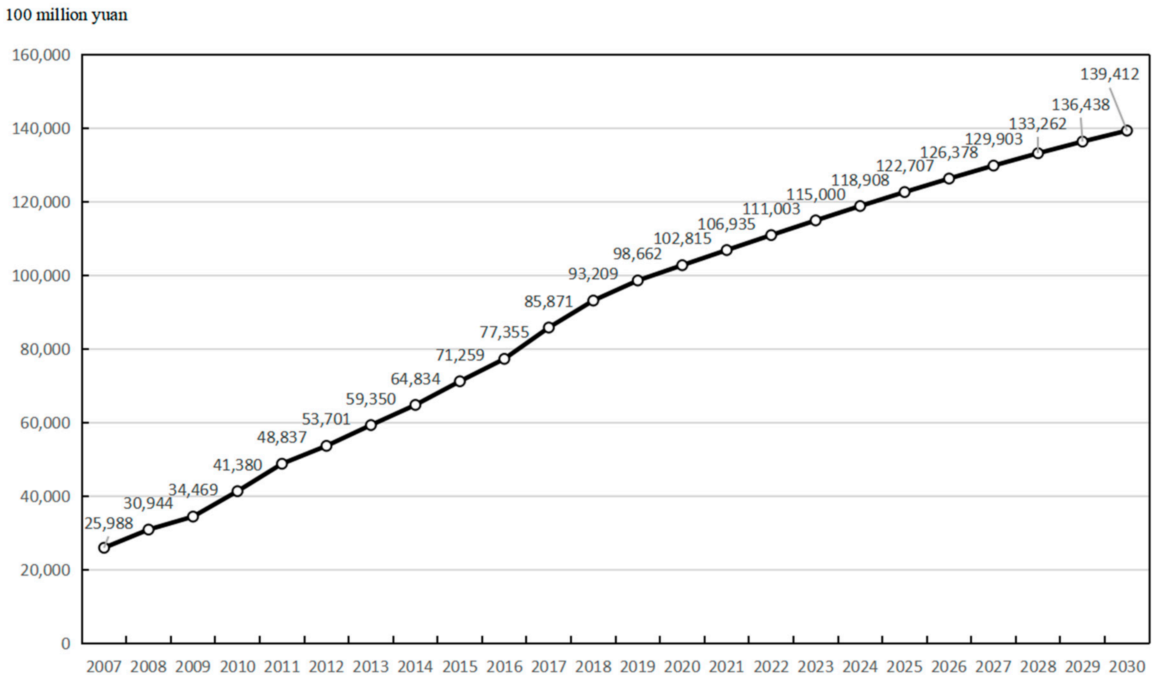

Figure 6. Simulation of the base scenario GDP for Jiangsu Province.

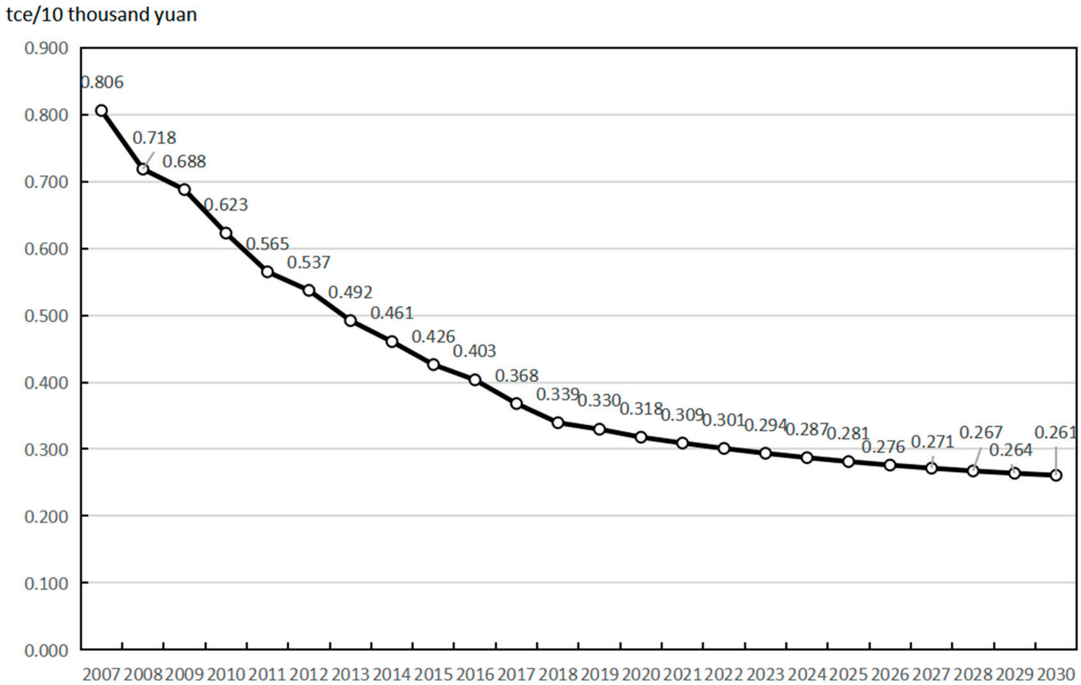

Figure 7. Simulation of energy consumption per unit of GDP for the base scenario in Jiangsu Province.

Figure 5 shows the increasing trend of low-carbon development level after the system dynamics simulation results, which is in line with the results of the previous comprehensive evaluation, and shows its low-carbon development level is increasing as well as responding to the national "double carbon" policy.

As can be seen from Figure 6, the GDP simulation for Jiangsu Province for the next ten years shows that the GDP is still growing, but the growth rate of GDP has become smaller in the last two years due to the recurring COVID-19 pandemic and other reasons. In the simulation of this system, the GDP of Jiangsu Province in 2030 is expected to reach 13,941.2 billion yuan, an increase of 30.37% compared to 2021.

Figure 7 shows the simulation results for energy consumption per unit GDP in Jiangsu Province, which shows a continuous reduction in the overall trend, in line with our expectations. The State Council's *Action Plan for Carbon Peaking before 2030* mentions energy usage per unit GDP ought to be reduced by 13.5% by 2025 compared to 2020, and Jiangsu Province has clearly indicated its intention to respond positively. In the simulation of this system, Jiangsu Province will have an 11.47% reduction by 2025 compared to 2020, and a 7.27% reduction by 2030 compared to 2025, which needs to be improved urgently.

4.4.2. Simulation of Scenarios

In the simulation of scenarios, there are four scenarios which are as follows: one is the base scenario, which means that the status quo continues to develop as a base control group without artificial changes. This scenario is a simulation of the current situation; the second is the economic development type, where GDP is important for all kinds of development in a region, so the focus is on the adjustment of the GDP growth rate. This scenario focuses on economic development; the third is the energy conservation type, in which the focus is on adjusting the total energy consumption of the system to observe all variables. This scenario focuses on observing the change of low-carbon development level when there is energy conservation; the fourth is the green transformation type, in which this system focuses on the degree of green transformation by increasing expenditure on environmental protection and energy efficiency. This scenario depends on the level of regional investment and emphasis on green industry.

The base scenario of this system predicted that the GDP growth rate, total energy consumption, and expenditure on energy conservation and environmental protection in Jiangsu Province in 2030 will be 2.18%, 363.68 million tce, and 57.35 billion yuan, respectively.

In the economic development type, the GDP growth rate of Jiangsu Province is slowed down considering that it gradually enters the new normal from 2011 to 2020. Therefore this system chooses the GDP growth rate in 2019 before the epidemic (5.85%) as the faster growth rate in the next ten years, i.e., the GDP growth rate in 2030 (relative to 2029) is set to 5.85% in this system, at which point the GDP of Jiangsu Province will reach 16,925.3 billion yuan in 2030; then, energy consumption per unit GDP is previously known from this system forecast, and will drop by 17.91% in 2030 compared to 2020, from 318 tce/million yuan to 261 tce/million yuan, thus adjusting its total energy consumption in 2030 to 441.75 million tce in the system according to this coefficient. Considering this scenario while the economy is developing, energy conservation and environmental protection expenditure will also develop; therefore, we chose the highest 0.43% in the fifteen years, and thus we set the energy conservation and environmental protection expenditure in 2030 to 72.78 billion yuan in the system, according to this proportion.

In the energy conservation type, the calculation shows that the average annual growth rate of GDP in Jiangsu Province predicted by this system from 2021 to 2030 is 2.99%; thus, this system will set the GDP growth rate in 2030 to 2.99% as the normal economic development, at this time the GDP of Jiangsu Province in 2030 will reach 14,557 billion yuan; and the energy consumption per unit of GDP is required to be reduced by 13.5% in 2025 compared with 2020 in the *Action Plan for Carbon Peaking before 2030*. In order to better achieve the target set by the central government, the study calculates energy consumption per unit GDP in 2030 as a 30% decrease compared to 2020, which is twice the target of 2025 and rounds up to an integer, that is, from 318 tce/million yuan to 222 tce/million yuan, thus adjusting its total energy consumption in 2030 to 324.04 million tce according to this coefficient; similarly, in the energy conservation type, taking into account factors such as the development of technology and science, the proportion of environmental protection and energy conservation expenditure in 2030 is also calculated using the previous maximum of 0.43%, so at this point the system according to this proportion sets energy conservation and environmental protection expenditure in 2030 at 62.60 billion yuan.

In the green transformation type, the system sets the GDP growth rate in 2030 to maintain the same 2.99% as the energy conservation type; energy consumption per unit of GDP continues to be predicted according to the normal reduction of 17.91%; then, total energy consumption is 379.94 million tce. Jiangsu Province's environmental protection and energy conservation expenditure ratio is currently lower than the national; therefore, it can be seen that from 2007 to 2021, the proportion of energy conservation and environmental protection expenditure in China's GDP is on the rise as a whole, accounting for an average of 0.56% in the past 15 years, which is a target that can be pursued in Jiangsu Province. As a result, the proportion of both in Jiangsu Province in 2030 is modelled at this level, setting energy conservation and environmental protection expenditure in Jiangsu Province in 2030 at 81.52 billion yuan.

4.5. Results and Discussion of Simulations

The final results are shown in Figure 8, with "current", "gdp", "energy", and "green" representing the base case, economic development type, energy conservation type, and green transformation type, respectively. The simulation results can be essentially split into the following three phases: stage one is from 2021 to 2023, when the economic development type is just above the level of the base case, while the green transformation type is at the highest level; stage two is from 2023 to 2028, when the level of the economic development type keeps climbing and eventually overtakes the energy conservation type, getting rid of the lowest level in the initial stage; stage three is from 2028 to 2030, and it can be seen that the low-carbon development level of the economic development type continues to rise at this time, and by 2029, it is already the highest of all the scenarios, while the green transformation type and the energy conservation type are steadily developing.

Through these, we can find that the economic development strategy, although initially less significant in terms of its contribution to low-carbon development levels, has strong momentum in the long term; the energy conservation strategy has been a moderate development with gradual improvement; and the green transformation strategy has been good overall, with the high level of its initial low-carbon development being an important reason.

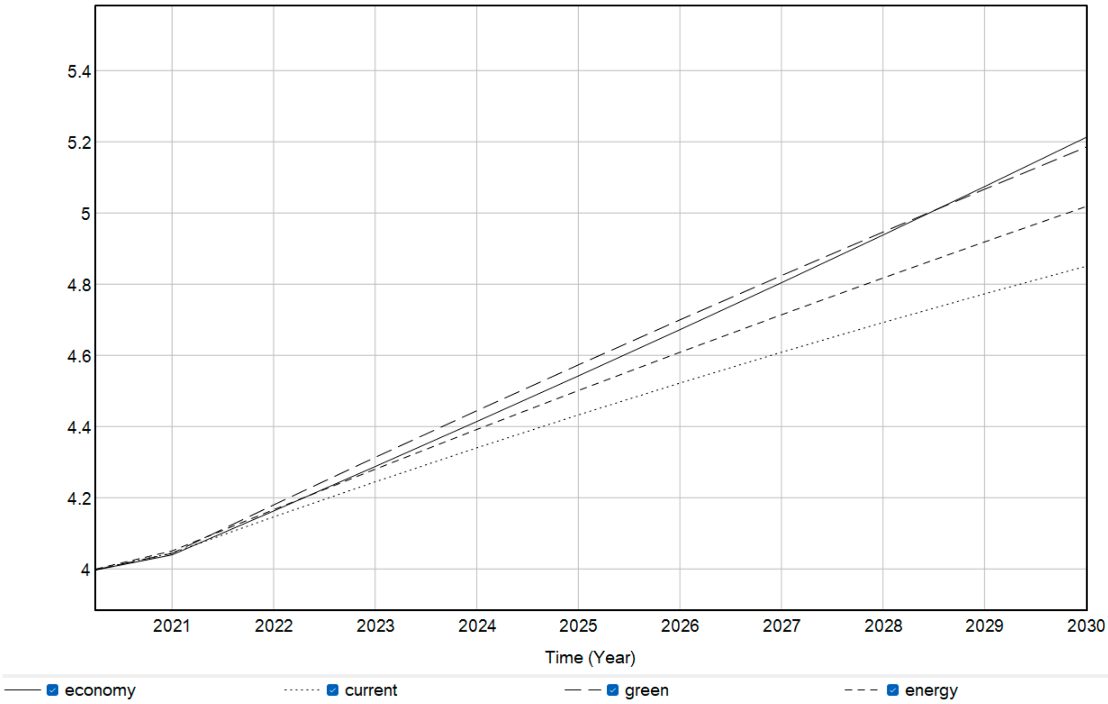

Figure 8. Simulation of scenarios of low-carbon development level in Jiangsu from 2020 to 2030.

5. Conclusions and Recommendations

5.1. Conclusions

In this paper, on the basis of constructing the indicator system, a comprehensive evaluation of low-carbon development level is carried out, and a simulation model of low-carbon development level is established by applying the system dynamics method, and the reliability of the model is good. By simulating the low-carbon development level under various scenarios and observing these differences in its dynamic changes, the paper finally reveals the effects produced by different combinations of strategies.

According to the calculation results, Jiangsu Province has attained certain achievements of late years, and the low-carbon development level steadily increases, from 1.44 in 2007 to 4.14 in 2021. The study determined that the "coordination force" is particularly critical, outperforming the other indicators in terms of both overall and average annual growth rates, and playing an important role in low-carbon development. Among its secondary indicators, the weight of "energy conservation and environmental protection expenditure/GDP" is the largest and should be maintained. The next best performer is "growth force", which is second only to "coordination force" in terms of overall growth over the decade 2007–2021. Next, "Transformation force" also performs better, with a difference of less than 0.02 between the total growth rate over the fifteen years, and is the highest of all the forces in 2021.

In the simulation, the results of the base scenario show that the overall green development of Jiangsu Province is good, but the decrease in energy consumption per unit GDP is slightly insufficient, so some measures should be taken to expand the degree of decrease. In the simulation of scenarios, the low-carbon development level in the energy conservation type has been developing steadily and gradually increasing. The low-carbon development level in the green transformation type, although not dominating the three combined scenarios in the end, is initially high and steadily increasing, again a measure that cannot be ignored to increase the low-carbon development level. The economic development type is a rapid development, starting with a level development just above the base scenario, and eventually reaching the highest level in 2030, with the greatest benefits in the long term, again demonstrating the importance of "growth force", which has great potential. Taken together, the three special scenarios have different effects on low-carbon development, and Jiangsu Province should balance economic development with energy conservation and green-related investment.

5.2. Recommendations

(1) Optimizing industrial structure and promoting low-carbon industries.

Under the "double carbon" goals, promoting low-carbon development in Jiangsu Province is a new task and an urgent requirement by means of industrial structure optimization and upgrading. It is a fundamental part of low-carbon development to adjust and change industrial structure, which can promote the development of growth force and enhance the level of economic development type. First of all, Jiangsu Province should make full use of its advantages of a solid foundation in the real economy, abundant scientific and educational resources, and vigorously develop high-technology industries such as big data, Internet+, artificial intelligence, and so on. Secondly, Jiangsu Province should also use the "Three new" economy (new industries, new formats, and new business models, including building economy, block economy, and headquarters economy) as a grip to promote the upgrading and transformation of traditional industries. Once again, Jiangsu Province needs to accelerate digital economy development as a key to transformation, and fight the battle for the advanced industrial base and modernization of the industrial chain. Finally, Jiangsu Province should also focus on intelligent reconstruction and digital transformation, and strive to build advanced manufacturing clusters such as new energy equipment, high-end new materials, and realize the transformation and upgrading.

(2) Accelerating the transformation of energy structure and promoting low-carbon and green energy.

The results of this study show that transformation force and coordination force have contributed in relatively large amounts to the improvement of low-carbon development, and secondary indicators for these two forces suggest that the structural transformation of energy sources is an effective means of strengthening these two aspects. Jiangsu Province is a major energy consumer, with a large share of coal consumption and a low share of green energy. Firstly, Jiangsu Province should cut down the proportion of fossil energy little by little, promote the development of photovoltaic power generation, wind power, hydrogen energy, and so on, achieve the efficient and clean use of coal, and enhance the capacity of new energy consumption. Secondly, Jiangsu Province can increase energy efficiency and promote the optimal combination of new energy and coal through technological innovation, and strive to achieve the transformation from "double control" of intensity and total amount of energy consumption to "double control" of carbon emissions. For example, the government can accelerate the promotion and application of new energy vehicles, improve the construction of new energy charging equipment, and provide subsidies for the purchase of new energy vehicles. Finally, Jiangsu Province should seize the opportunity to accelerate the transformation of traditional high-energy-consuming industries like building materials and steel, as well as increasing the proportion of low-energy-consuming industries such as high-tech manufacturing, so as to promote the achievement of the "double carbon" target in an orderly manner.

(3) Developing a green economy and promoting sustainable development.

The green transformation type in the simulation of scenarios is not sustainable enough as it fails to maintain a superior low-carbon development level at the late stages, although it is high in the early stages. Expenditure on energy conservation and environmental protection in Jiangsu Province has been around 0.4% of GDP from 2011 to 2020, compared to the national average of 0.6% in 2011–2020. It is shown that Jiangsu Province is slightly under-invested in green capital, and should invest more in the future to build industrial clusters such as high-end equipment, environmental protection and energy conservation, strengthen energy-saving and green renovation projects, fix the weak links and shortcomings in ecological protection, energy and water conservation, and promote low-carbon sustainable development. The government ought to construct numerous energy conservation and environmental protection demonstration parks, actively encourage the rehabilitation of existing structures to save energy, the integration of photovoltaic construction of buildings, and raise the percentage of vehicles powered by new energy used in urban public transportation, taxi, logistics, sanitation, and cleaning vehicles.

From the aspect of resource utilization, Jiangsu Province should vigorously develop a circular economy, implement green and circular transformation projects, and promote the recycling of express packaging, new energy vehicle batteries, and so on. With reference to consumption, a green lifestyle should be established in Jiangsu Province. This is to ensure low-carbon sustainable development by strictly conserving water and electricity resources, comprehensively promoting a water-saving and energy-saving society, and raising residents' low-carbon awareness.

5.3. Limitations

Firstly, this paper sets three different scenarios based on the current situation and policies in Jiangsu Province, and more scenarios and regions can be simulated in the future.

Then, the quantitative analysis needs to be detailed. Due to the difficulty in data acquisition, some relevant influencing factors will inevitably be missed. In the future, more detailed investigations can be carried out and more objective indicators and their weight determination methods can be explored.

Finally, this paper takes Jiangsu Province as a whole as the research object, and does not have the ability to analyze the differences in various regions of the province, which leads to certain limitations in relevant suggestions. In the future, further research can be carried out according to the development characteristics of various regions in the province.

Author Contributions: F.L.: Conceptualization, methodology, validation, resources, writing—review and editing, supervision, project administration, funding acquisition. Y.Z.: methodology, software, formal analysis, investigation, data curation, writing—original draft, data availability. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: This study does not involve any human participants, human data, or human tissues.

Informed Consent Statement: We confirm that the manuscript has been read and approved by all named authors. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

Data Availability Statement: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Values of all secondary indicators during 2007–2021.

Indicators	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
GDP per capita (yuan)	33,798	39,967	44,272	53,525	61,464	66,533	72,768	78,711	85,871	92,658	102,202	110,508	116,650	121,333	137,039
Industrial upgrading (none)	0.674	0.698	0.732	0.783	0.820	0.859	0.918	0.972	1.017	1.092	1.091	1.114	1.169	1.202	1.156
Per capita disposable income (yuan)	11,574	13,237	14,653	17,006	19,820	22,432	24,776	27,173	29,539	32,070	35,024	38,096	41,400	43,390	47,498
Proportion of coal consumption (%)	68	66.6	63.3	64	70.8	68.7	68.4	64.4	64.0	64.2	60.2	57.4	54.7	52.8	55.3
Proportion of installed capacity of new energy generation (%)	0.92	1.12	1.68	2.26	3.29	4.17	5.49	7.44	9.92	12.14	14.91	18.63	20.49	24.55	28.78
Investment in urban environmental infrastructure development (+) 100 million yuan	160.98	185.6	232.8	300	350.55	380.26	509.94	579.31	452.12	453.2	363.63	444.06	403.88	515.77	422.98
Number of green patent applications (pieces)	2561	4117	6433	9155	12,770	18,056	20,454	23,440	29,363	37,593	47,262	55,067	45,838	52,900	58,689
Number of industrial waste gas treatment facilities (sets)	10,431	11,365	11,508	11,631	16,065	17,641	17,964	19,179	22,037	25,652	31,500	32,530	30,622	27,627	27,438
Number of R&D researchers (persons)	259,177	315,461	369,403	406,231	455,135	549,159	626,882	676,526	699,614	761,046	754,228	794,123	897,701	914,510	1,088,300
Energy consumption per unit of GDP (tons of standard coal/10 thousand yuan)	0.806	0.718	0.688	0.623	0.565	0.537	0.492	0.461	0.426	0.403	0.368	0.339	0.330	0.318	0.361
Energy conservation and environmental protection expenditure/GDP (+) %	0.174	0.317	0.428	0.338	0.349	0.361	0.386	0.367	0.433	0.369	0.340	0.341	0.378	0.328	0.289
Per capita park green area (m^2)	12.59	13.13	13.21	13.29	13.3	13.6	14	14.4	14.6	14.8	15	14.7	15	15.3	15.6
Per capita comprehensive water consumption (hundred million m^3)	722.91	719.27	703.20	701.74	693.26	680.07	608.98	580.48	553.93	540.72	553.10	544.86	582.59	534.02	544.35
Percentage of days with good air quality (%)	49.7	51.4	53.2	55.1	57.0	59.0	60.3	64.2	66.8	70.2	68	68	71.4	81	82.4
Public transport vehicles per 10,000 people (sets)	11.55	12.41	11.71	11.5	12	11.7	12.7	14.1	15.1	15.5	16	16.6	17.1	17.6	17.4

Appendix B

R language software code:

```
install.packages("xlsx")
library(xlsx)
install.packages("rospca")
library(rospca)
newnew<-read.csv("standard.csv", header=T, row.names=1)
robnew<-robpca(newnew, k=2)
diagPlot(robnew)
robnew$loadings
robnew$eigenvalues
write.table(robnew$loadings, "D:/new.xlsx", row.names=T, sep="\t")
```

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